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CONTROLO Portuguese Conference on Automatic Control, Guimarães – Portugal, Sept. 2016.

http://link.springer.com/chapter/10.1007/978-3-319-43671-5_61

ISBN: 978-3-319-43670-8

DOI 10.1007/978-3-319-43671-5_61

João Ferreira, Hugo Martins, Manuel Barata, Vítor Monteiro, João L. Afonso, "*OpenADR - Intelligent Electrical Energy Consumption towards Internet-of-Things*", CONTROLO Portuguese Conference on Automatic Control, Guimarães - Portugal, pp.725-736, Sept. 2016. DOI: 10.1007/978-3-319-43671-5_61 ISBN: 978-3-319-43670-8 (Print) 978-3-319-43671-5 (Online)

OpenADR - Intelligent Electrical Energy Consumption towards Internet-of-Things

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Abstract. With the growing of intermittent renewable energy sources, like wind and solar, are required energy backup solutions to establish an advantageous compromise between the energy production and consumption. Typically, these renewable energy sources are not installed at the end-users level, which can create the problem of uncontrolled distributed energy sources. In this research work we propose a solution based on the standard OpenADR to handle this problem, creating a platform based on internet-of-things capable to turn-on or off electrical devices based on a central decision process that meets the requirements of energy producers and consumers. Producers can provide energy according to the consumer's requirements and take part of energy production and costs fluctuations. Based on an OpenADR standard for energy data exchange and a central cloud server, a list of services are provided to handle this transactions, with georeferenced information to minimize energy losses in the distribution process.

Keywords: OpenADR, Decision Process, Smart Grid, Distributed Energy Sources

1 Introduction

Distribution Generation (DG) penetration into Distribution Network (DN) has been increasing quickly due to the introduction of home production based on renewable energy sources. This DG raises concerns about the matching between production and consumption. Thus, it is in best interest of all players involved to allocate them optimally (energy production and consumption) such that it will increase reliability, reduce system losses, and improve the voltage profile while serving the primary goal of demand supply [1]. System losses can also be reduced through capacitor banks to locally supply a portion of the reactive power [2,3]. Most of literature is based on the assumptions that load is fixed and that the output of DG units is dispatchable and controllable [4]. These assumptions are inaccurate, because the uncertainties related to load and renewable based generation (wind and solar) are not considered. The available power from renewable based generation can ensure the restoration of some of customers affected in case of fault, improving overall system reliability. DN are normally meshed in design but operated radially. In on first step we transform this DN into a georeferenced graph in a process that we are able to calculate the distribution distance among several points in the distribution network. This approach allows us to decide based on a minimum loses process supplying loads at the minimum cost, increasing system security and reliability and enhancing power quality [5]. Significant research regarding losses minimization in the area of network reconfiguration of distribution systems has been done [6-9]. DN reconfiguration and optimal power flow problems have been addressed and studied separately by many works reported in the literature, but they have scarcely been studied at the same time applied with the same model and using in the calculation process a deterministic optimization and decomposition optimization technique [10]. This DN is transforming and evolving into a potentially more controllable grid than in the past, the so-called "Smart Grid" (SG) [11-13]. DN reliability in SG context is one of the major areas for DN design and operation. In this context and using the available standard openADR2.0 provided by the OpenADR Alliance to construct an open source Virtual End Node (VEN) client to retrieve Demand Request (DR) signals from a central point based on production availability. This approach allows to control remotely client equipment at users home to adjust real time production to consumption. Users define equipment that can work on this condition based on a defined profile, examples of these VENs are: electric vehicle, washing machines, heating systems, and air-condition. From this approach, two main benefits could be achieved. The first, in the client side, are defined the equipment that can respond to signals from the energy provider to minimize their energy use at times when the power grid is under stress from high demand, or even to shift some of their power use to times when power is available at a lower cost. This appliances will also be able to respond to signals from your energy provider to avoid using energy during times of peak demand. Users can benefit from lower prices, using this approach. The second, in the production side, adjustment of production offer without big investments to store production excess.

DR program aims to reduce the peak hour consumption and the shift demand to off-peak hours, through the two-way IP communication flow between suppliers and consumers, the grids can also adapt more readily to the increased penetration of renewable energy sources and encourage users' participation in energy savings and cooperation through the DR mechanism. Effective DR depends on the demand management and price/load/renewable energy forecasting, which call for sophisticated signal processing and optimization techniques. In Fig. 1, we show two faces of DR: (1) when the total electricity demand remains inconstant and a financial incentive reduces peak load, this is named peak clipping; and (2) on other side, load shifting features a fixed total demand, but where demand can be shifted forward or backward in time to off-peak hours. In additional to this renewable energy sources introduces production uncertainty which changes periodically this behavior.

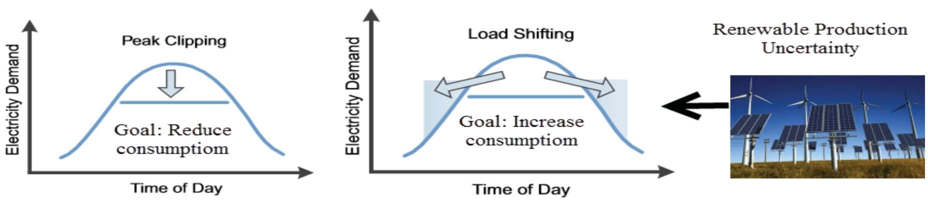

Fig. 1. Comparison between peak clipping and load shifting considering the intermittent energy production from renewable sources.

2 OpenADR

Automated Demand Response (ADR) describes a web-based control system that triggers DR events automatically by signaling other pre-programmed control systems and with the available production resources.

OpenADR2.0, an open communication protocol specifically designed for DR, is gaining momentum in the U.S., Asia and Europe. Initially developed by Lawrence Berkeley Nat. Lab OpenADR2.0 is now supported by an influential Alliance while more and more vendors integrate it into their technical products. Some vendors acting in the building energy management business start implementing OpenADR2.0 from design phases. OpenADR is certified by OASIS and has recently been approved as a Publicly Available Specification (PAS) by the International Electrotechnical Commission (IEC). A working group is also working on a harmonization between OpenADR2.0 and Common Information Model (CIM) [14].

The OpenADR protocol is a communication IP network to handle energy consumption requests based on production availability. Based on the Demand Response we centralize all transitions process between Virtual Top Node (VTN, identifies the entity that manage VENs) and Virtual End Node (VEN, client energy consumer or producer). Based on the graph of distribution network, a hierarchical relation is performed between VTN and VEN, see Fig. 2. . VTN performs the role of Virtual Power Plant (VPP) manager. A VPP consists of an aggregation of Distributed Energy Resources (DERs). The VPP Manager centralize transitions from VEN with load resources that they interact and performed decision about loads ON/OFF based on distribution distance, previous calculated in georeferenced graph. . This VPP receive information about production resource available and based on the demand response try to fit the resources do VEN needs with the goal of minimization power losses and non-supplied energy. All local Micro Generation (MG) can be handled as a VEN with a report service based on a metric device.

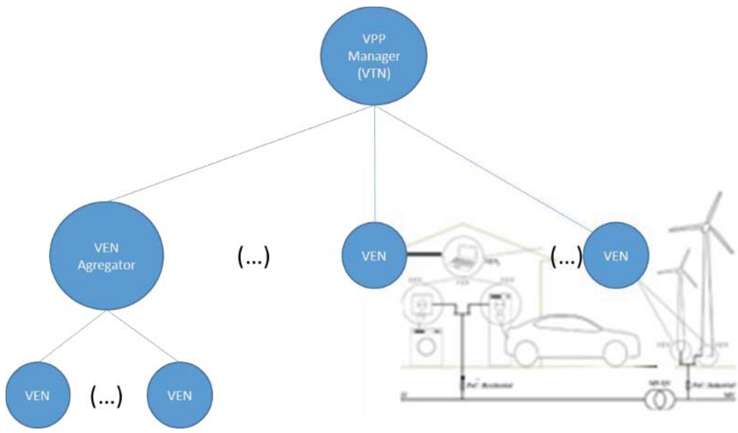

Fig. 2. VEN and VTN interaction with georeferenced position. VTN centralize information in a hierarchical process.

2.1 Functionalities available for stakeholders interaction

OpenADR 2.0 supports the following services from OASIS EI Version 1.0 standard or subset thereof. Extensions to these services are included to meet the DR stakeholder and market requirements. A list of central available services is described at OpenADR (http://www.openadr.org), like logical request-response services. We create a new service, the distance distribution calculation, which output is the distance of VEN to other energy resource based on a georeference graph for the electrical DN. The main problem of this approach is the work involved in the identification of georeference of each of these points on the DN. Having collected this information any geographic database can easily handle the problem. Main idea for decision process of electrical distribution is the real distance on the DN. The area with the distribution of the electrical network is manually transformed in a graph (see Fig. 2), where it is added geographic information and power limitations between the nodes. Each node is identified the distance and the distance is calculated between geographic coordinates of VTN and VEN matching to this nodes. Fig. 2 shows this distribution network transformed to a georeferenced graph with dependencies. When a VEN is registed a distance calculation is performed to other VEN. For that we need all distribution nodes georeference.

2.2 Security

For all message exchanges in OpenADR, use of Transport Layer Security (TLS) with client authentication is mandated for mutual authentication as well as message integrity and confidentiality protection. The OpenADR 2.0 specification requires all nodes (both VTNs and VENs) to be equipped with public/private key pairs and digital certificates issued by a trusted Certificate Authority (CA), which implies that vendors have to pay nominal per-device cost for issuance and management of certificates. Communicating peers are required to authenticate each other by using the digital certificates.

Regarding authentication of VENs, the OpenADR specification requires to use the identifier of the VEN (venID) and some unique information derived from the VEN's digital certificate, e.g., a SHA fingerprint of the certificate. In order for a VTN to verify that a sender of an incoming message is actually the VEN whose venID is claimed in the payload, the VTN should perform validation of a one-to-one mapping between the venID and the digital certificate.

2.3 VEN - Virtual End Node

The VEN has operational control of a set of resources/processes and is able to control the electrical energy demand of these in response to an understood set of messages (i.e., DR signals). The VEN is able to communicate (2-way) with a VPP receiving and transmitting messages that relate to power grid situations, conditions, or events.

Consumers define the number and type of electrical appliances of the house from a pre-defined list. Tree main operation classes are defined based on operation's needs:

- Class 1: Schedule-Based Appliances – Concerns with the electrical appliances time periods of operation. Since in the houses there are appliances with flexible operation time, like washing machines, dryers and dishwashers, users can define their operation time according to the best options in terms of energy availability.

- Class 2: Range Temperature Based Appliances – For equipment with temperature range, like refrigerators, heating systems or air conditioners, users can define the ranges, and the VPP manager will try to fit it based on energy availability.
- Class 3: Battery-Assisted Smart Appliances – The electric vehicle charging processes can be scheduled and controlled to adapt to energy availability.

VENs can also be energy producers that integrate a diversity of players: conventional electricity producers, renewable energy producers and home users with MG. The main sources of energy in a MG are wind and the sun, and the electrical energy is obtained through micro wind turbines and solar photovoltaic panels. These sources of energy are the most common and the easier to implement in the MG. Presently, this produced energy is provided to the electrical power grid without any concern about the Energy Market (EM) or the electrical power grid capability to receive energy.

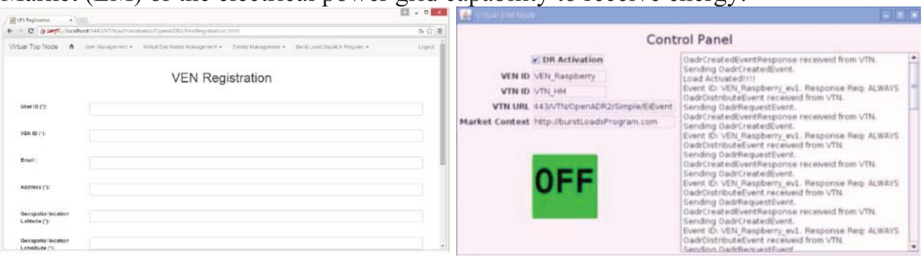

Fig. 3. Example of a web interface for VEN registration processes and VEN Web client interface where all information about this VEN transaction is displayed.

2.4 VTN - Virtual Top Node

Nodes in these networks are divided into two groups: nodes that publish and transmit information about events to other nodes (e.g., utilities), and nodes that receive the communications respond to that information (e.g., end-users). The upstream nodes that publish information about upcoming events are called Virtual Top Nodes (VTNs); the downstream nodes that receive this information are called Virtual End Nodes (VENs). In this context, the VTN manage the VEN's resources based on geographic location of the generations resources look for nearest loads resources (based on electrical distribution distance) and activate loads consumption. Due to proximity between generation resources and loads we have less loss in transmission process.

The VENs with generation resources, send information about energy availability to VPP manager and establish communication between pre-defined VEN (main condition is the distribution distance). The OpenADR signals are transported via standards-based Internet Protocols (IP) such as Hyper Text Transfer Protocol (HTTP) or XML Messaging and Presence Protocol (XMPP).

2.5 Electric Vehicle as a UPS

Electric Vehicles (EVs) also represent an increase in energy consumption that could be used to capture renewable energy generation and help to balance generation with demand, theoretically making electricity marginally cheaper and cleaner. Vehicle-Grid-Integration (VGI) technologies encompass this approach. At the University of Minho was developed a new operation mode that consists in the detection of a power outage in the power grid and the change of the EV battery charger control to operate as an off-line UPS [15]. This charging system with the introduction of VEN concept since the EV can handle more electric power. At user home, the EV can be charge with different profiles from the power grid of 240 V-15 A. There is already a diversity of EV, such as Nissan Leaf with a 24 kWh battery pack and autonomy of 160 km (value considering a careful drive style). Volt's has a battery pack of 16 kWh. Once there is a diversity of EV with different battery power, we assume that in average we have 15 kWh available and in a for the energy market. Also there is a diversity of hybrid vehicle with low batteries capacities so we will assume the value of 10 kWh with a market penetration of 10%. So our simulation handles a local VPP of 300 end-users with 30 EVs, each of then with 10 kWh. With the EV market penetration, the goal of flat power consumption (Fig. 1) is possible to be achieved at night periods (when the majority of EVs are at home plugged in at charging process). Consumption variations, as well as intermittent production due to renewable sources, can be dealt by the central control process, with production excess being used in the charging of EVs, and during production deficit the energy can be taken from EVs (operation in V2G – Vehicle-to-Grid mode). EVs can act as controlled load or generation resource, using a smart charging process, as explained and exemplified in [16,17].

3 Implementation of an OpenADR Infrustructure with RaspberryPi(s) towards Internet of Things

Since most fabricant do not provide an OpenADR yet or because the existence of old equipment, we developed a cheap solution around $25. Fig. 4, shows the product developed to create the VEN for a load or MG. RaspberryPi was configure to act as a VEN. In the Fig. 4, we simulated on/off operation through a LED but in real VEN operation this command is used to put on/off equipment or to slow\increase heat or cooling process. Also this can be used as a VEN with a generation resource where we add metering capability, display information is optional because information is stored as local HEMS (Home Energy Management System) and can be presented through a web application. Since most electrical appliances are not compliant with OpenADR a VEN of Fig. 5 should be integrated. All resources send information to local HEMS (Home Energy Management System) that was developed for VENs configuration interfaces and visualization of energy exchanges. Based on VENs definition a consumption profile is created where we add non OpenADR consumptions. This is basically a web interface application that interacts with local VENs. This consumption profile are important information to apply in a future work data mining approach to extract knowledge related with energy consumption.

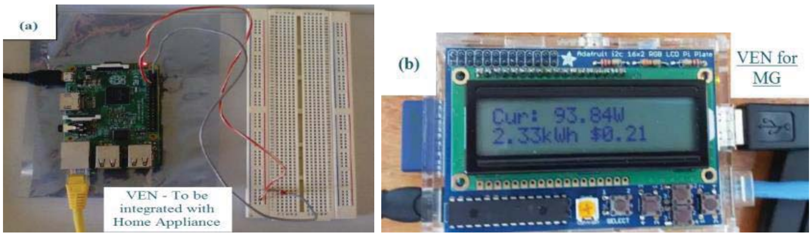

Fig. 4. Developed RasberryPi VEN (a) and VTN for MG (b).

Since is not easy to have a real scenario for testing, we simulated our approach creating several VENs and multiply the effect to have impact in electricity consumption. Regarding production we use real data from 3 days (28 a 30 Abril 1015) from Portuguese REN [18]. Also consumption patterns were available and a dynamic approach were performed to match production to consumption based on a central commands performed remotely at the VEN. We introduce a small scale VEN (ten) distributed geographic.

The first step is the VEN registration through a web application (Fig 4(a)). In this register process the user defines the VEN class, working hours, consumption and geographic position. The simulation tool loads a request from the local VPP server, using the production and consumption data. If the consumption is above a predefined value, then an off remote command is performed, and if the production is high enough a remote on command is given. We perform small scale tests, with ten VEN, and with a simulation of production and consumption based on historical data. From these tests, several procedures of remote turn on/off of VEN were performed. We also have tested with success the decision of VEN on/off based on distribution distance of the VEN to the energy source and priority VEN class (see section 2.3). The case of class 2 (for example, range temperature in a heating system), when temperatures goes down the value defined by the user, it assumes maximum priority, were also tested. Fig 5 shows the VEN interface and associated transactions when it is turned on and when it is remotely turned off, because there was no need to take electricity production excess. Fig. 6 shows a web interface to local HEMS, where the user can check all actions and consumption performed by the VEN that he is the owner.

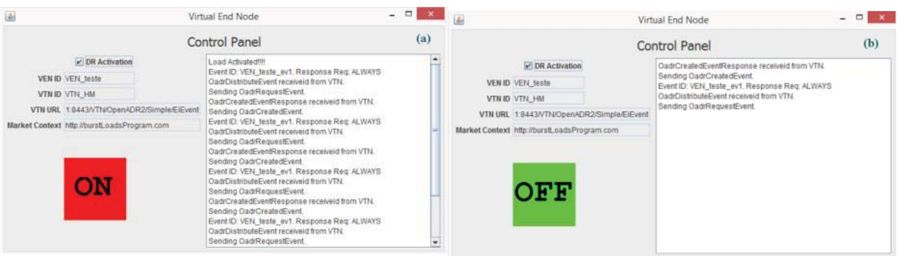

Fig. 5. VEN interface and associated transactions: (a) Turned on; (b) Turned off.

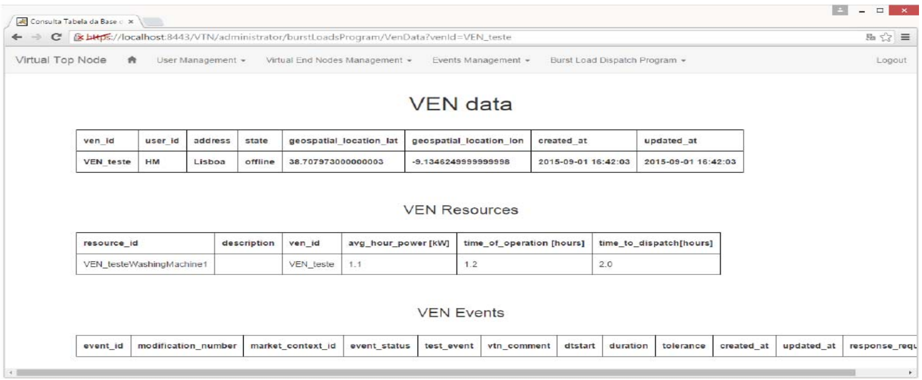

Fig. 6. VEN's available reports with information stored at local VPP.

For MG, owners register the VEN, defining the renewable capacity, geographic localization and the report service poll interval with the energy produced and/or average power. Local device informs about the MG production that was not consumed. In our test environment we simulated VPP manager (VTN) based on historical energy production available from [18]. All the energy production is collected at central VPP manager for main producers and local MG production. Based on this information, the VPP manager takes the decision for the VEN being on/off, or for the VEN increasing or decreasing the power consumption. This decision is based on VEN class and distribution distance between VEN´s generation resources and VEN's loads resources. So, based on production data and consumption data available from [18], a simulation process was taken.

It is possible to check the power consumption per house. Fig. 7 shows an example where, at 12 hour, one of the houses is not taking the energy produced, and therefore, this energy is delivered to the power grid. In this case, a nearest VEN with a load in off position was turned on automatically in order to consume energy. Also, it can be seen that at 15 hour the consumption is negative (the house is injecting energy in the grid). This information is send to a local VPP manager, and a decision process takes place in other that a VEN or a set of VENs need to be turned on.

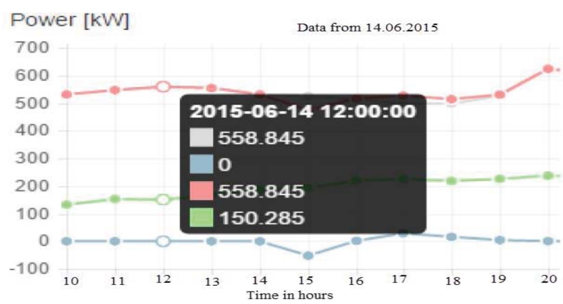

Fig. 7. Home consumption stored at local VPP with graphic web interface for user presentation.

4 Conclusions

Distributed Energy Resources (DER), small-scale power generating technologies close to energy loads, are expected to become an important part of the future electrical power system [17]. OpenADR plays an important role in this process, allowing consumption events based on external events, like production availability, that is reflected in energy price. The distribution systems account for the higher percentage of system losses compared with the higher voltage transmission systems, and since DER are installed near the loads, they cause an improvement in the overall efficiency of the system. DER has the problem of variability (changes in load), uncertainty (supply contingencies) and unpredictability (renewable generation). The main important fact is that Demand Response (DR) can handle local Micro Generation (MG) production excess, and users can tune their consumer behaviour in part based on MG production, i.e., they can develop a collaborative process based on energy production information, starting/stopping electrical appliances that do not have an obligatory time constrain.

DR is becoming a growing part of the resource base that electrical system operators rely on to maintain the reliability of the electrical power grid. Market liberalization, economic pressures, and environmental regulations are all moving toward a path of fewer traditional central power plants and more DER to address future energy needs. Advanced technologies can help speed up this transition and make it more reliable. Automated Demand Response (ADR) describes a system that automates the DR dispatch process, from the grid operator to the DR aggregator (if involved) to the end-use customer – all without any manual intervention. Navigant Research forecasts that global spending on ADR will grow from $13 million in 2014 to more than $185 million in 2023 [19].

The upcoming reality of Smart Grids will need to join efforts from different fields of knowledge. In this research work we have joined two groups with different expertise, one at ISEL in Informatics and Telecommunication, and the other at the University of Minho in Energy and Power Electronics, with previous works on power quality, renewable energy and electric vehicle charging systems.

Acknowledgements

This work has been supported by COMPETE: POCI-01-0145-FEDER-007043 and FCT – Fundação para a Ciência e Tecnologia within the Project Scope: UID/CEC/00319/2013.

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